

# TRMM-TMI satellite observed soil moisture and vegetation density (1998–2005) show strong connection with El Niño in eastern Australia

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Received 7 April 2007; revised 24 May 2007; accepted 5 July 2007; published 4 August 2007.

[1] Spatiotemporal patterns in soil moisture and vegetation water content across mainland Australia were investigated from 1998 through 2005, using TRMM/TMI passive microwave observations. The Empirical Orthogonal Function technique was used to extract dominant spatial and temporal patterns in retrieved estimates of moisture content for the top 1-cm of soil ( $\theta$ ) and vegetation moisture content (via optical depth  $\tau$ ). The dominant temporal  $\theta$  and  $\tau$  patterns were strongly correlated to the El Niño Southern Oscillation Index (SOI) in spring ( $r^2 = 0.90$ ), and to a progressively lesser extent autumn, summer and winter. The Indian Ocean Dipole (IOD) index also explained part of the variation in spring  $\theta$  and  $\tau$ . Correlation analysis suggested that the regions most affected by El Niño are mainly located in eastern Australia. The results suggest that the drought conditions experienced in eastern Australia since 2000 and clearly expressed in these satellite observations have a strong connection with El Niño. **Citation:** Liu, Y., R. A. M. de Jeu, A. I. J. M. van Dijk, and M. Owe (2007), TRMM-TMI satellite observed soil moisture and vegetation density (1998–2005) show strong connection with El Niño in eastern Australia, *Geophys. Res. Lett.*, 34, L15401, doi:10.1029/2007GL030311.

## 1. Introduction

[2] Australia is subject to frequent droughts, resulting in significant impact on the economy and environment [Horridge *et al.*, 2005]. Inter-decadal phases of wetter and drier conditions are observed in rainfall records [Beeton *et al.*, 2006]. Many areas have been experiencing extraordinary drought conditions since 2000. There are questions about the possible causes of this drought: an extreme event, natural climate cycling, and/or a consequence of human-induced climate change. Rainfall patterns have been linked to several ocean circulation indicators: droughts to sea surface temperature anomalies (SSTA) over the eastern Indian Ocean [Streten, 1981, 1983]; winter rainfall patterns in western and southern Australia to the Indian Ocean Dipole (IOD) [Ashok *et al.*, 2003]; southeastern Queensland rainfall to central Pacific Ocean SSTA [Murphy and Ribbe, 2004]; and the 2001/02 drought to a modest El Niño event [Nicholls, 2004]. Spatial patterns, interactions, and changes in the connection between rainfall and different aspects of ocean circulation need to be better understood [Abram *et al.*, 2007] to put the current drought in appropriate context and allow statements about future drought frequency and severity to be made with greater confidence.

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[3] Soil moisture and vegetation conditions are strong indicators of antecedent weather conditions, ecosystem state and drought [McVicar and Jupp, 1998]. They can be inferred from satellite observations, by making use of the spectrally distinct behavior of chlorophyll in green canopies in the visible and near infrared wavebands [Campbell, 2002] and/or that of water in biomass and top soil in the near to thermal infrared and microwave spectra [Choudhury, 1993; Fensholt and Sandholt, 2003; McVicar and Jupp, 2002]. Observations of passive microwave emissions have certain advantages, in that: (1) they are available regardless of cloud cover; (2) there is a physical relationship relating emissions to water amounts in the environment; and (3) rather than the land surface only, they provide information on water content of the top soil layer (albeit still only a few cm deep). Potential disadvantages are the coarse resolution of observation ( $>10$  km) and the lack of a consistent and continuous observation program over the past decades. A recently developed approach to retrieving surface parameters from microwave emissions can be used for all bands in the microwave domain [de Jeu and Owe, 2003; Owe *et al.*, 2001; Wagner *et al.*, 2007; Owe *et al.*, 2007], allowing data collected by different satellites since 1978 to yield a time series covering 30 years.

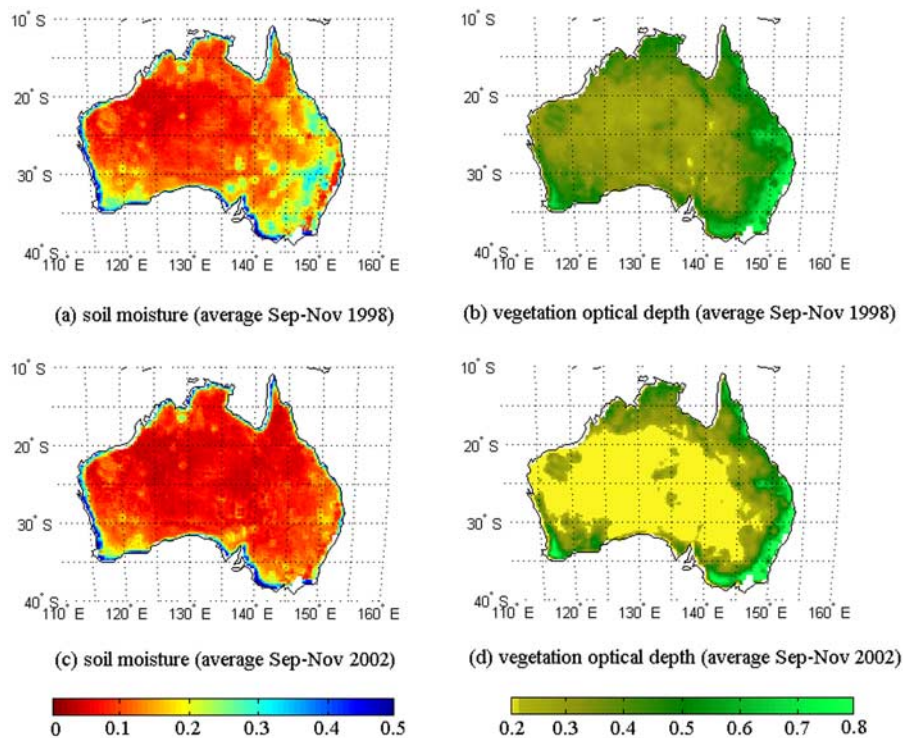
[4] As a first step in determining the potential use of such a longer time series, we explored the link between three ocean circulation indicators and spatiotemporal patterns in soil moisture and vegetation condition for an 8-year data set of passive microwave derived soil moisture and vegetation condition recently developed by Owe *et al.* [2007].

## 2. Data and Methods

### 2.1. Data

[5] The Microwave Instrument (TMI) on board NASA's Tropical Rainfall Measuring Mission (TRMM) has provided operational passive microwave measurements at 10.7 GHz (X-band) and eight higher frequencies including the 37 GHz (Ka) band since December 1997 [Kummerow *et al.*, 1998]. The observations can be assimilated in a microwave radiation transfer model to infer soil moisture, and a set of atmospheric, soil and vegetation variables, including soil and canopy temperature and vegetation optical depth.

[6] We used the top soil moisture content ( $\theta$  in  $\text{m}^3 \text{m}^{-3}$ ) retrieved using the Land Parameter Retrieval Model (LPRM) [Owe *et al.*, 2001; de Jeu and Owe, 2003; Meesters *et al.*, 2005] and X-band brightness temperature. The retrieved soil moisture represents roughly the top 1-cm, because TMI with the low observing frequency of 10.7 GHz (X-band) has a source depth of about 1 cm. It has been evaluated against various observational and simulated datasets, generally with good results and with an absolute accuracy of ca.  $0.06 \text{ m}^3 \text{m}^{-3}$  [Owe *et al.*, 2001; de Jeu and Owe, 2003; O'Neill *et al.*, 2006; Wagner *et al.*, 2007].



**Figure 1.** Average soil moisture ( $\theta$  in  $\text{m}^3 \text{m}^{-3}$ ) in top 1-cm of soil and vegetation optical depth ( $\tau$ ) for a wet spring (September–November 1998) and a dry spring (2002) across mainland Australia.

[7] Vegetation optical depth ( $\tau$ ) is a dimensionless parameter that can be interpreted as being directly proportional to vegetation water content [Jackson and O'Neill, 1990; Jackson and Schmugge, 1991] and was derived according to Meesters *et al.* [2005].

[8] The retrieved soil moisture and vegetation optical depth data were resampled and aggregated into seasonal average  $0.25^\circ$  resolution images for December 1997 through December 2005 for mainland Australia. Two spring seasons - one wet, the other dry - are shown in Figure 1. Areas where observations are influenced by open water or snow are left white.

[9] The ocean circulation indicators used in this study were the Southern Oscillation Index (SOI), the North Atlantic Oscillation (NAO) and the Indian Ocean Dipole (IOD) Mode Index. The SOI is obtained from the Bureau of Meteorology of Australia (<http://www.bom.gov.au/climate/current/soihtml.shtml>), IOD index from the Japan Agency for Marine-Earth Science and Technology (<http://www.jamstec.go.jp/frsgc/research/d1/iod/>) and NAO index from the National Oceanic and Atmospheric Administration (NOAA, [ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele\\_index.nh](ftp://ftp.cpc.ncep.noaa.gov/wd52dg/data/indices/tele_index.nh)). The SOI used is the standardized anomaly of the mean sea level pressure difference between Tahiti and Darwin (Troup SOI) [McBride and Nicholls, 1983]. Saji *et al.* [1999] defined the IOD index as the sea surface temperature difference between the tropical western Indian Ocean ( $10^\circ\text{S}$ – $10^\circ\text{N}$ ,  $50^\circ\text{E}$ – $70^\circ\text{E}$ ) and the tropical southeastern Indian Ocean ( $10^\circ\text{S}$ –equator,  $90^\circ\text{E}$ – $110^\circ\text{E}$ ). The NAO index is constructed by comparing daily 500 mb height anomalies over the Northern Hemisphere to monthly mean 500 mb air pressure height for 1950 through 2000 [Barnston and Livezey, 1987].

#### 4. Discussion and Conclusions

[16] For the period 1998 through 2005, we found a strong correlation between seasonal soil and vegetation moisture content derived from passive microwave obser-

vations and SOI, particularly for eastern Australia in spring, and also for autumn and summer. In addition, we found a signal relating both  $\theta$  and  $\tau$  to IOD in spring and the strongest correlation between  $\theta$  and  $\tau$  in spring and autumn. For most of the continent, these seasons coincide with the transition between dry and wet season (or vice versa) and associated with this the greening and senescence of annual vegetation. Delays in these transitions associated with oceanic circulation patterns may explain the stronger correlation. The influence of ENSO on rainfall has been documented [e.g., McBride and Nicholls, 1983; Allan *et al.*, 1996], as has that of IOD [Simmonds, 1990; Drosowsky, 2002; Saji *et al.*, 1999]. The spatial patterns of ENSO influence on soil moisture agree well with those found in rainfall (cf. maps based on interpolated station rainfall on <http://www.bom.gov.au/climate/enso/ninocomp.shtml>). Our results provide further evidence that ENSO, and to a lesser extent IOD, can also be linked to the drought conditions experienced since 2000. It shows that the ENSO/IOD influence on rainfall is also evident in the soil moisture and vegetation record.

[17] Without using station rainfall records, we were able to directly delineate regions experiencing the strongest influence of ENSO during the period analyzed. The most affected regions are in the Murray-Darling Basin and Queensland; both are important agricultural regions.

[18] It is noted that the time series analyzed covers only the moderate 2002 El Niño event (although spring 2004 could be considered a very weak event when using a less strict definition). Development of a longer time series of global data of soil moisture, vegetation optical depth and surface temperature compiled from different passive microwave observation sources should help to identify whether the high correlations found in this study are maintained and to better understand seasonal and inter-annual variations in climate associated with ocean circulation patterns.